The Gamma–Ray Burst Monitor for Lobster-ISS

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Abstract

Lobster-ISS is an X-ray all-sky monitor experiment selected by ESA two years ago for a Phase A study (now almost completed) for a future flight (2009) aboard the Columbus Exposed Payload Facility of the International Space Station. The main instrument, based on MCP optics with Lobster-eye geometry, has an energy passband from 0.1 to 3.5 keV, an unprecedented daily sensitivity of $2{\times}10^{-12}$ erg cm^{-2} s^{-1}, and it is capable to scan, during each orbit, the entire sky with an angular resolution of 4–6 arcmin. This X–ray telescope is flanked by a Gamma Ray Burst Monitor, with the minimum requirement of recognizing true GRBs from other transient events. In this paper we describe the GRBM. In addition to the minimum requirement, the instrument proposed is capable to roughly localize GRBs which occur in the Lobster FOV (162×22.5 degrees) and to significantly extend the scientific capabilities of the main instrument for the study of GRBs and X-ray transients. The combination of the two instruments will allow an unprecedented spectral coverage (from 0.1 up to 300/700 keV) for a sensitive study of the GRB prompt emission in the passband where GRBs and X-Ray Flashes emit most of their energy. The low-energy spectral band (0.1-10 keV) is of key importance for the study of the GRB environment and the search of transient absorption and emission features from GRBs, both goals being crucial for unveiling the GRB phenomenon. The entire energy band of Lobster-ISS is not covered by either the Swift satellite or other GRB missions foreseen in the next decade.

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1. Lobster–ISS

Lobster-ISS (Fraser et al., 2002) is an X-ray mission proposed by an International collaboration led by George Fraser (University of Leicester, UK) in response to the ESA call for two flexi-missions (F2 and F3) for the International Space Station (ISS). The project was approved for an industrial phase A study funded by ESA (kick-off in July 2002, contractor Carlo Gavazzi Space, Milano) for the accommodation of the experiment aboard the ISS

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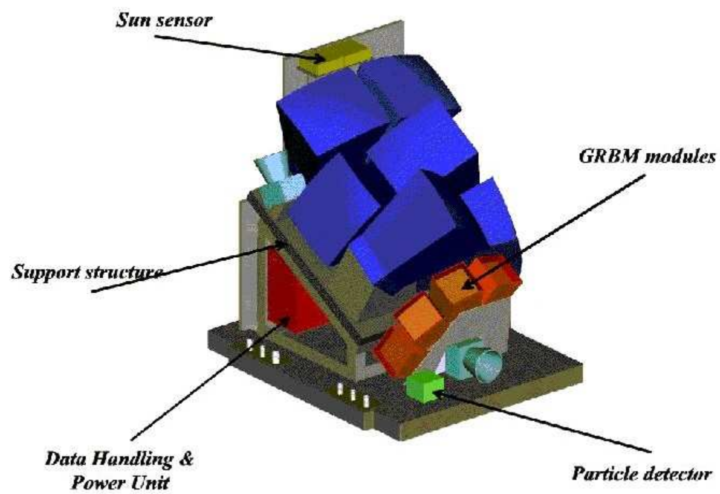

Fig. 1. Sketch of the Lobster payload. The location of the GRBM modules is indicated (courtesy of Carlo Gavazzi Space).

Columbus External Payload Facility (CEPF), with its launch in 2009 and a 3 year duration flight. The phase A study, with an additional extension of two months decided by ESA in order to allow a better investigation of few issues, has been now successfully completed. Unfortunately, given the new policy by NASA about ISS, the prospects of the Lobster-ISS flight are uncertain. Because of this, other flight opportunities, like another payload facility aboard ISS or a free–flyer satellite, are being investigated.

The main scientific objective of Lobster-ISS is the mapping of the X-ray sky in the 0.1–3.5 keV energy band with an angular resolution as low as 4–6 arcmin and a daily sensitivity of 2×10^{-12}erg cm^{-2}s^{-1} . The main instrument is based on Micro-Channel Plate (MCP) optics in a Lobster-eye configuration and focal plane detectors based on special sensitive proportional counters. It is composed of six identical modules, each with a Field of View (FOV) of $27^\circ\times22.5^\circ$, misaligned in such a way to give a total rectangular field of view of 22.5° in the direction of the ISS motion and 162° in the perpendicular direction. Thanks to the orbital motion of the ISS, it will be possible to map almost all the sky every orbit, allowing the production of a catalog of 250000 X-ray sources every two months. The combination of the wide field of view, the good angular resolution and the high sensitivity will allow the study of the time behaviour of all classes of X-ray sources, from comets to stellar coronae, X-ray binaries, soft X-ray transients, SNe explosions, AGN, diffuse X-ray background and Gamma-Ray Bursts (GRBs).

Given that many classes of sources (e.g., flare stars, compact X-ray binaries) are emitters of short transient events, the separation of GRBs from other X-ray short events is a hard task for an instrument with a passband from 0.1 to 3.5 keV. In order to overcome this issue, a Gamma Ray Burst Monitor (GRBM) flanks the Lobster-eye telescope. In this paper we describe the GRBM proposed for the phase A study, its science goals and performance.

2. The Lobster-ISS GRBM: scientific goals and design

The GRBM we propose not only satisfies the minimum requirement of identifying true GRBs, but it extends significantly the science objectives

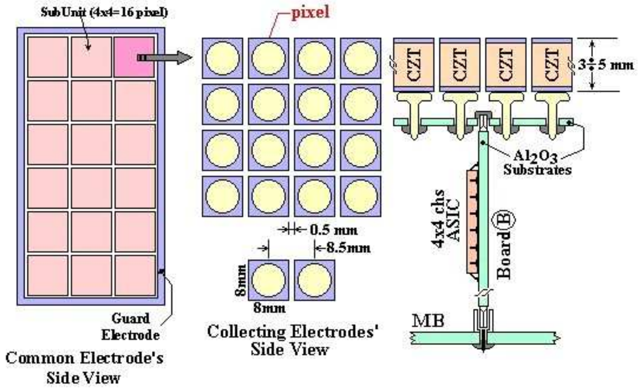

Fig. 2. A possible assembly of a CZT-Unit and of a CZT Sub-Unit (16 CZT elementary detectors) is shown. The mother board connects CZT sub–units and also houses the analog post processing electronics.

of the Lobster-ISS mission. It consists of 4 misaligned detection units, each one made of an array of Peltier-cooled CdZnTe (CZT) detectors, surmounted by a passive collimator which defines the field of view. The FOV of each unit is $35^\circ \times 55^\circ$ (FWHM), resulting in a total rectangular field of view of 35° in the direction of the ISS motion and 240° in the perpendicular direction. Each collimator is made of four slabs of 1.5 mm thick Tungsten with a graded shield to minimize the X–ray fluorescence. To get the above FOV, the height of each slab is required to be 14.2 cm. The use of collimators allows the reduction of the (primary and atmospheric) background radiation entering through their aperture, and reconstruction of the burst position within a few degrees (for strong GRBs) from the different direction of the collimator axes. With this instrument configuration, a source is viewed by at least 2 detection units for most (95%) of the directions within the FOV of Lobster. As a consequence, the area exposed by the GRBM to these directions ranges from 0.70 to 1.30 times the useful area of a single detection unit.

A sketch of the possible Lobster–ISS payload configuration is shown in Figure 1, where the blue and red modules correspond to the X–ray telescope and the GRBM, respectively. Each detection unit (see Figure 2) is made of an array of CZT elementary crystals (pixels) (e.g. Caroli et al., 1999). Each pixel has a cross section of 8×8 mm^2. The elementary crystals are packed together in sub-units of 4×4 pixels, while each detection unit is made of 3×6 sub-units. Thus the X-ray sensitive array is made of 288 pixels. The active area of each unit is 184 cm^2 while its geometric area, which takes into account a 0.5 mm pitch between each couple of pixels, is 208 cm^2. The crystals are assembled on thin (1 mm) ceramic plates. Below each module is located the front-end electronics with multiplexers and ADCs. The detector thickness, which was assumed for the phase A study in order to guarantee an instrument passband from 3 to 300 keV, is 5 mm. We are evaluating the extension of the energy passband up to 700 keV either by increasing the CZT thickness up to 10 mm or by using an alternative detector. The very valid alternative to the CZT is a phoswich-like detector made of a silicon drift chamber coupled with a CsI scintillator, the development of which is underway (e.g. Marisaldi et al., 2004). The scientifically relevant specifications of the baseline configuration of the GRBM are summarized in Table 1. In the case of GRB detection, the GRBM electronics and onboard data handling provide high resolution spectra and light curves. The GRB position is also determined on board and automatically transmitted to the Lobster data handling electronics for a better determination by means of the X-ray telescope.

Table 1
GRBM scientifically-relevant specifications

No. of units	4
Detection area/unit	184 cm^2
Energy band	3–300/700 keV
Instantaneous field of view	35° x 55° (FWHM)
	(per module)
	35° x 240° for 4 modules
Total exposed area to a given point	from 129 to 240 cm^2
Detector	Cooled (∼250 K) CZT
Energy resolution	$\Delta E/E \sim 3\%$ @ 6 keV
Minimum (non-zero) exposure time	∼1150 s
for a given point, per orbit	

Thanks to the GRBM, the Lobster-ISS passband extends from 0.1 to 300/700 keV, an un-

precedented energy band never used by an all-sky monitor to study the prompt emission of GRBs. The very good energy resolution of the GRBM, 3% at 6 keV, will permit a sensitive study of transient absorption and/or emission features during the early phase of the prompt emission. Moreover, the combination of the two instruments will allow an unprecedented study of the absorption cut–offs below 2 keV in the GRB spectra. As demonstrated by BeppoSAX (Amati et al., 2000; Frontera et al., 2001, 2004), the study of these features and cut-offs is of key importance for the determination of the circumburst environment properties, the nature of progenitors and the connection with SNe. The proposed GRBM, given its multi-pixel configuration, can also be exploited to measure the polarization of the GRB prompt emission by optimizing the CZT thickness for this goal (e.g. Curado da Silva et al., 2004). In the described configuration, Lobster-ISS is also the ideal mission for studying X-Ray Flashes (XRFs) and their nature (Kippen et al., 2001; Barraud et al., 2003). In addition to GRBs and XRFs, the GRBM will allow identification and study of all types of fast high energy X–ray transients, in particular of the Soft Gamma Repeaters (Feroci et al., 1999; Guidorzi et al., 2004).

3. Expected performances

3.1. *Background and sensitivity*

The mean background level which is expected at the ISS orbit for the instrument configuration described above is reported in Table 2. It has been estimated by summing the contributions of the diffuse X–ray background and the intrinsic (particle–induced) background. The intrinsic background spectrum is assumed to have a power law shape with count index of -1.4 (value based on past experience) and normalization derived from the assumption that the count intensity in the 30–200 keV range is $3{\times}10^{-3}$ cts cm^{-2} s^{-1} . Given the wide field of view of the GRBM, the contribution of bright galactic sources to the total background level is not negligible. In particular, when the Galactic Bulge is inside the FOV of a detection unit, the background level is expected to increase by about 30%. This has been taken into account in the estimates and simulations reported below. The 5σ sensitivity to GRB events is reported in Table 2. Given that a GRB in the FOV of the Lobster telescope is viewed by at least 2 GRBM detection units, we assumed the background level corresponding to an area of 2 x 184 = 368 cm^2 . Conservatively, we assumed for the area exposed to the source the minimum value of 129 cm^2, corresponding to 70% of the area of each detection unit (see Sect. 2). As source spectrum we assumed a typical Band function (Band et al., 1993) with $\alpha = -1$, $\beta = -2$ and $E_0 = 200$ keV. The 5σ sensitivity of the GRBM to a Crab-like source as a function of exposure, again assuming a total illuminated area of 129 cm^2, is shown in Figure 3 for the cases of a source located in the galactic center region and of a source with high galactic latitude. We note that, by means of an off–line refined analysis, we expect to be able to identify the pixels (or groups of pixels) illuminated by the source. In this case the detection area contributing to the background level will be reduced to that exposed to the source and the instrument sensitivity will be significantly improved with respect to the values reported in Table 2 and Figure 3.

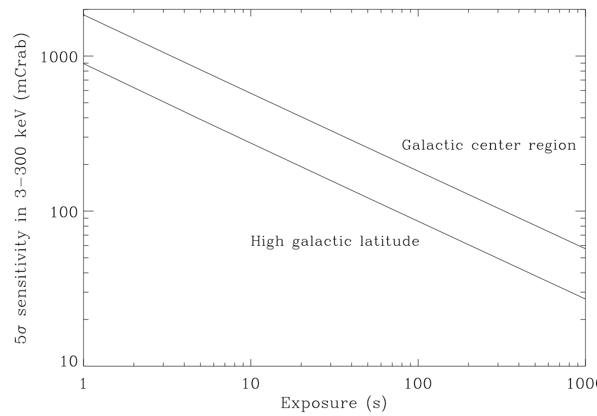

Fig. 3. Expected 5σ sensitivity of the GRBM to a Crab–like source as a function of exposure time. Two cases have been considered: a source located in the galactic center region and source at high galactic latitude.

Table 2
Expected background level and 5σ sensitivity to GRB events, computed by assuming a typical GRB spectrum.

Energy band (keV)	Background (cts cm^{-2} s^{-1})	Flux sensitivity (photons cm^{-2} s^{-1})	Flux sensitivity (10^{-8} erg cm^{-2} s^{-1})
3–10	6.7	2.0	1.8
10–30	2.1	1.2	3.5
30–200	1.0	0.85	10
50–300	0.6	0.68	13

3.2. *Source localization and discrimination*

The simulated source localization accuracy (90% confidence level, c.l.) as a function of the burst fluence in the 50–300 keV energy band ranges from ~1–2° for the brightest events to several tens of degrees for the weakest ones. In these simulations we assumed the values of the total detector area illuminated by the source, background level and source spectrum assumed for the flux sensitivity evaluation. We used the source localization reconstruction algorithm expected to be used during the flight and based on that adopted for the BeppoSAX/GRBM (Guidorzi et al., 2001).

As mentioned in Section 2, the minimum requirement for the GRBM is its capability of identifying true GRBs. To this end, exploiting the BeppoSAX experience, we intend to set a constraint to the hardness ratio (HR) between the count rates in two energy bands (Guidorzi et al., 2001). By means of numerical simulations, we find that the significance of the ratio between the expected count rates in the 30-70 keV and 70-200 keV energy bands is sufficient to allow the discrimination between GRBs and other transient events, in the range of fluences and durations detectable with the Lobster telescope in 1 s.

3.3. *Sensitivity to spectral features*

One of the main goals of the present GRBM configuration is the possibility of detecting transient absorption features during the rise time of the GRB events. Such features, possibly associated with a variable column density, are predicted by several models and have already been observed in two GRBs (Amati et al., 2000; Frontera et al., 2004). The joint fitting of the GRBM and Lobster spectra will extend the analysis down to 0.1 keV, allowing not only the study of the column density behaviour with time, but also the increase of the edge significance. In Figure 4 we show the spectrum expected to be detected by the GRBM for Lobster-ISS using as template that measured, with the BeppoSAX WFC plus GRBM, from GRB 990705 during the first 13 s. The presence of the feature is visible at much higher statistical significance than that observed with BeppoSAX (Amati et al., 2000).

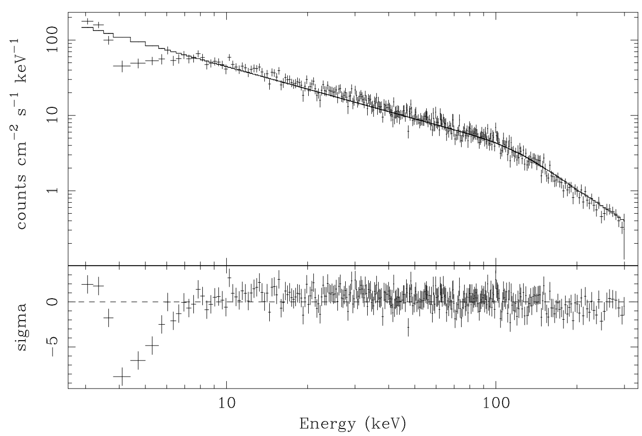

Fig. 4. The spectrum of GRB 990705 in the first 13 s (Amati et al., 2000) as expected to be measured with the proposed GRBM for Lobster-ISS. The absorption edge at ~3.8 keV is apparent at a $> 12\sigma$ significance.

In addition to absorption features, also transient emission components are expected to contribute to the early GRB emission, in particular black–body emission from the photosphere of the fire-

ball. Evidence of such a transient broad emission component was actually found in the prompt emission of GRB 990712, and could be modeled with a blackbody with temperature kT$\sim$1.3 keV (Frontera et al., 2001). We simulated a GRBM spectrum by assuming as template the spectrum of GRB 990712 in the time interval in which the transient emission feature was observed. The excess with respect to the power-law continuum is detected at $\sim 8\sigma$ significance. As above, for these simulations we assumed a total exposed area of 129 cm^2 (worst case).

3.4. *Sensitivity to polarization*

The polarization measurement of the prompt gamma-ray emission from GRBs is recognized to be one of the major objectives of GRB studies, being of key importance to establish the emission mechanism of the radiation (e.g. synchrotron, inverse Compton). For this purpose, it is important to measure: i) the spectral dependence of the linear polarized fraction and ii) the temporal dependence of the position angle. These quantities would allow to clearly identify the emission mechanism, the geometry of the advected magnetic field and the origin of the light curve variability. In addition, it is clearly of primary importance to measure the level of polarization in the GRBs for which the observed spectrum is supposed to be in violation of the synchrotron properties. With the present configuration, for a GRB with 25-100 keV fluence similar to that of GRB 021206 (2.9×10^{-5} erg cm^{-2}, Coburn & Boggs, 2003), the expected minimum detectable linear polarization is $\sim$60% in the 70–150 keV energy range and $\sim$30% in the 150–300 keV band.

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